BTeV High Gradient Quadrupoles
Superconductor RFP Update
(JCT for G. Ambrosio)

Plan:

- Use LHC IR quadrupole specifications (aka SSC) as basis
  cross section unchanged ➔ conductor geometry must be unchanged
  Inner Strand: SSC-M35-000014
  Outer Strand: SSC-Mag-M-4146

- Review and modify if/as needed
  deal with BTeV specific issues

- Vendor to provide finished product: cable
  in the LHC program some cable was made at LBNL, some at NEEW

Issues:

- Cable instability in LHC program: 'popped strands' during coil fabrication (Oxford strand); can lead to shorts during fabrication ➔ 'springback' a candidate?

- Ramp rate (dI/dt sensitivity of I_q); due to interstrand resistance?
  Tevatron ramp rate change above ~8000A? *(not a problem for LHC ramp rates)* ➔ curing cycle a candidate?

- Potential change in insulation scheme (see F. Nobrega)
  'standard' insulation (kapton) potentially not available?
  small changes in coil properties? ramp rate sensitivity?

'Highlights' of Strand and Cable Specifications

Strand Electrical and Mechanical Properties

Property	Unit	Inner Strand		Outer Strand	
		Value	Tolerance	Value	Tolerance
Composition		Nb47+1wt.%Ti	Nb47+1wt.%Ti	Nb47+1wt.%Ti	Nb47+1wt.%Ti
Cu:SC		1.3	±0.10	1.8	±0.10
Ic (7T,4.22K)	A	**378**		**185**	
Diameter	mm		0.808±0.0025		0.808±0.0025
Filaments	μm		6.0		6.0
RRR			>70		>70
Anneal		None		None	
"n" Value (7 T)[α]			30		30
Twist Pitch	mm	13.1	±1.5	13.1	±1.5
Twist Direction		left		right	
***Sharp Bend Test*[β]**					
***Spring Back*[γ]**	degrees	<1150		<1150	

[α] SSC-Mag-T-9001; Critical Current

[β] SSC-Mag-T-9004; Sharp Bend Test Procedure

[γ] SSC-Mag-T-9005; Determination of Springback Properties

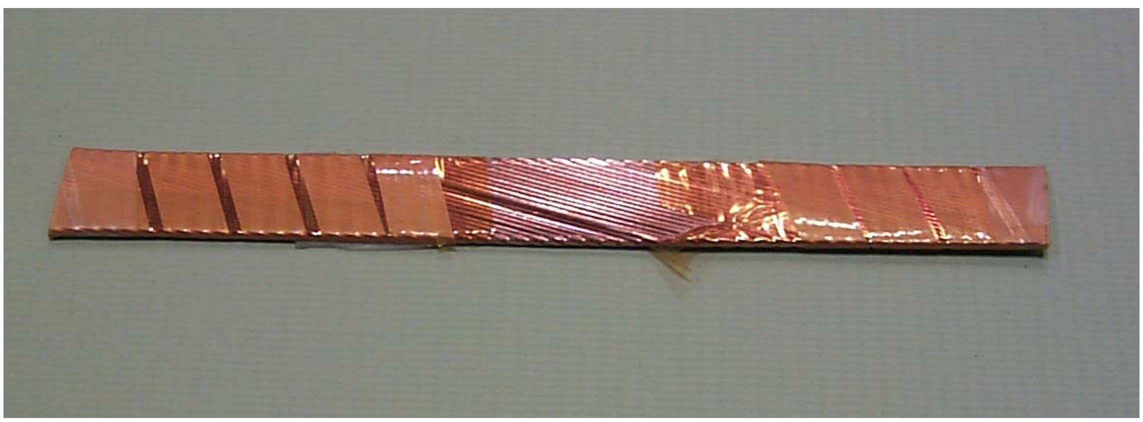
Cable Electrical and Mechanical Properties

Parameter	Unit	Inner cable		Outer cable	
		Value	Tolerance	Value	Tolerance
Number of strands		37	-	46	-
Cable width	mm	15.4	± 0.025	15.4	± 0.025
Minor edge	mm	1.32		1.051	
Cable Mid-thickness	mm	1.465	± 0.006	1.146	± 0.006
Major edge	mm	1.61		1.241	
Keystone angle	degree	1.079	± 0.05	0.707	± 0.05
Transposition length	mm	114	± 5	102	± 5
Lay direction		Right	-	Left	-
Minimum critical current	kA	14	-	8.5	-
Minimum unit length	m	180	-	200	-
Residual twist	degree	0 - 90		0 - 90	
Minimum bending radius	mm	7		15	

Springback:

- 'Spring-ier' strand more difficult to cable?
- Oxford strand – correlated with "popped strand" problem was near upper limit (1100) of acceptance criterion
- Alsthom strand – better behaved – also had a high springback value
- Cable lay (left/right) vs. winding direction data needs to be examined further; popped strand problem was with (mostly?) left lay cable
- Variation in springback, strand-to-strand, a possible culprit? (R. Scanlan) Needs to be understood...

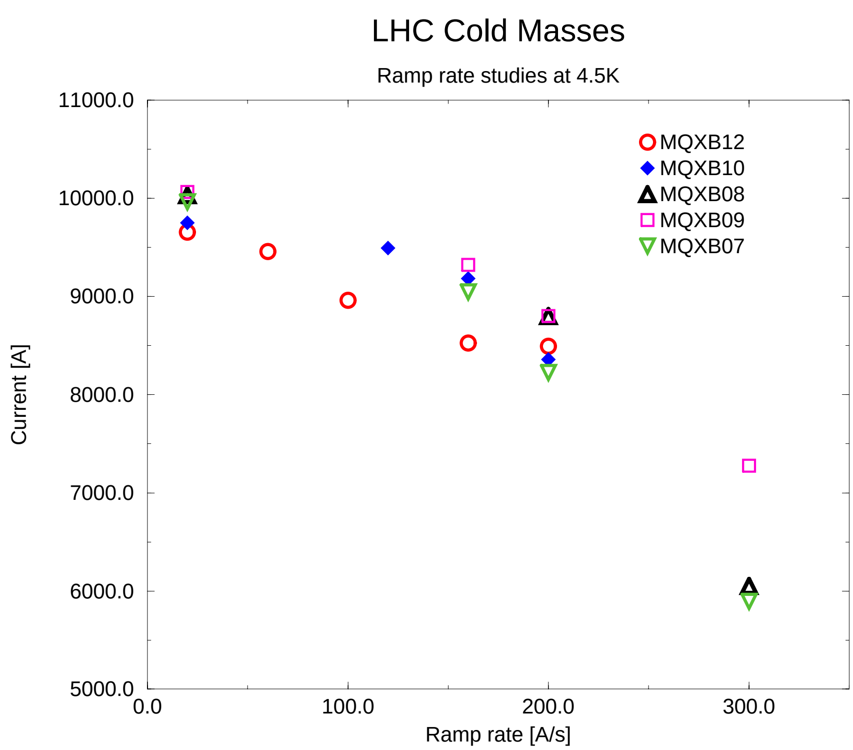
Popped Strand Example



(Pictures courtesy of Jim Rife)

Interstrand Resistance:

- Low interstrand resistance ➔ Eddy current heating ➔ ramp rate (dI/dt) dependence of quench current
- Resistance determined by strand surface condition, contact area, ...
- Affected by coil curing cycle: temperature and pressure; strand coating (if any), oxidation, annealing
- A change in insulation scheme could change curing cycle which could lead to a change interstrand resistance...



➢ **Giorgio has made a proposal to measure the interstrand resistance of the LHC conductor in a test of a collared coil section from an LHC cold mass:**

Specifications Status:

Items to resolve

Springback limit:
being evaluated – to date there is no clear evidence that simply lowering the value is a solution to popped strands; further details being pursued

Interstrand resistance: (ramp rate dependence)
being studied since changing the Tevatron ramp profile is possible but a non-trivial step; since this is determined by curing cycle as well as strand/cable preparation, it has NOT been a specification in our previous conductor/cable procurements. It could drive the price up (e.g.,strand coatings like LHC) as well as require additional studies

Insulation scheme:
Need to determine if LHC insulation will be available or if we will be forced to change. A change in the insulation/ adhesive/curing cycle could change the interstrand resistance as well as affect coil size and mechanical properties

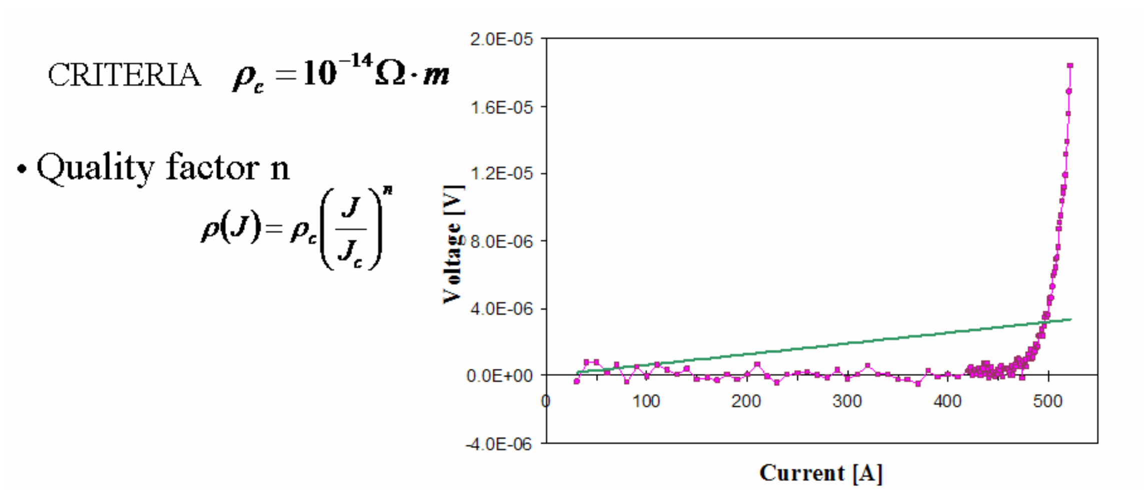
Proposal for testing the ICR (Interstrand Contact Resistance) of an LHC-IR quad coil section

9/16/2004

Goal: to know the average value of the ICR in the LHC-IR quads, using Alstom cable and standard coil assembly procedure. This value will be compared with the ICR value of LHC outer coils. **The comparison will tell if AgSn coating may be an interesting option for the BTeV quads or not.**
Method: The ICR is affected by several factors (strand and cable manufacturing, curing procedure, pressure at cold), in order to be the closest possible to the real condition in a magnet, the test will be performed at <u>4.2 K on collared coils</u> made of Alstom cable (best cable used for LHC-IR quads, coils made out of this cable showed lower ramp rate sensitivity than coils made out of OST cable). The selected coil should have been fabricated using the procedure used during magnet production.
Sample fabrication: there are two options:
Option 1) Use the coil from magnet MQXB??? that was cut. Cut four sections long about 20 cm each, put the parts together and collar them (as you do for a mech model). The collars should cover a length equal to the transposition pitch of the inner cable.
Option 2) Use Alstom inner cable from a spool too short to be used for a new coil and pile up the four sections. Cure them under pressure using the same procedure used for the magnet production, and assemble the sections together as in the previous option.
Sample instrumentation: the cables that will be measured (5 per test cycle) will be opened in order to have contacts only under the collars (one transposition pitch long). They will be instrumented as we are doing for the measurement of Nb3Sn coils (will be more easy because NbTi is not as brittle as Nb3Sn): two current leads at the edges of the cable and 8 voltage taps in between.
Test facility: we will use the cryostat with the large bore (7 and ¾ inch aperture) in the Superconductor R&D lab, and the instrumented flange that we are using presently for ICR measurement of Nb3Sn coils. This is going to require the fabrication of an adapting flange and a modification to the bottom part of the present sample holder (to accommodate the larger sample). The acquisition chart will be the one we are using now for Nb3Sn coils.

Example of Strand Short Sample Measurement Data

Straight line is the voltage limit from the resistivity criterion
Definition of the 'Quality Factor' n



Note: plot units are current and voltage; J=I/A, ρ = (V/I)(A/l) where A = strand cross sectional area, and l = length of strand between taps

SSC-Mag-T-9005
Determination of Springback Properties
(from R. Scanlan)

1. Purpose

   This test establishes a standardized method for testing superconducting (S.C.) wire to determine its springback acceptability.

2. Materials Required

   2.1 Cut three lengths, 1 m each, of S.C. wire to be tested.
   Note: Do not bend wire unnecessarily.

3. Test Equipment

   3.1 Springback Test Fixture or equivalent.

   3.2 2 kg weight

4. Applicable Documents

   Springback Test Fixture - DWG ###########.

5. Test Procedure

   5.1 Prepare one end of wire sample with a 13 mm, 90° bend, and tie the other end securely to a 2 kg weight.

   5.2 Test the spring fixture to be sure it turns freely.

   5.3 Thread the 90° bend through the test fixture and place in the hole in the spring winder with the locking pin in place.

   5.4 Tighten the wire.

   5.5 Make sure the 90° bend is not affecting the "Zero" reading and the wire is tangent to the spring winding shaft.

   5.6 Set "Zero" on the degree wheel.

   5.7 Hang the 2 kg weight over the end of the table. Release the clamp. Hold the spring winder handle and pull the locking pin.

5.8 Wind 10 complete turns and replace locking pin. Then tighten wire clamp.

5.9 Hold spring handle and remove locking pin. Gently let the spring unwind and note the number of revolutions.

5.10 Once the spring has stopped, gently touch the spring handle to make sure the spring is at equilibrium and has reached its full springback. Do not unwind the spring.

5.11 Note and record the total number of degrees of springback.

5.12 Cut the sample at the wire clamp and the 90° bend.

5.13 Carefully slide the spring winder out of its bearings and remove the sample.

5.14 Measure and record the inside diameter, label the sample and store in archives.

5.15 Three sections of each wire sample shall be measured and reported.

Test Method No. 8002-2 - Wire Springback Test

1. Purpose:

   This test establishes a standardized method for testing superconductor wire to determine its springback acceptability for cabling.

2. Materials Required:

   A 3-1/2 ft. length of superconductor wire to be tested.
   Note: Do not bend wire unnecessarily.

3. Test Equipment:

3.1 Springback Test Fixture or equivalent (Fig. 4005-2 #1).
See BNL Dwg. No. 25-718.01-3. This fixture is mounted on a horizontal surface.

3.2 (1.5 ± 0.1) pound weight.

4. Applicable Documents:

   None.

5. Test Procedure:

5.1 Prepare one end of wire sample with a 1/2 inch long, right-angle bend and tie the other end securely to a 1.5-pound weight.

5.2 Test the springback fixture to be sure it turns freely.

5.3 Thread the right-angle bend through the test fixture and place in the hole in the spring winder with the locking pin in place.

5.4 Tighten the wire.

5.5 Make sure the right-angle bend is not affecting the "0" reading and the wire is tangent to the spring winding shaft.

5.6 Set "0" on the degree wheel.

5.7 Hang the 1.5-pound weight over the end of the table. Release the clamp. Hold the spring winder handle and pull the locking pin.

5.8 Wind 10 complete turns and replace locking pin. Then tighten wire clamp.

5.9 Hold spring handle and remove locking pin. Gently let the spring unwind and note the number of revolutions.

5.10 Once the spring has stopped, gently touch the spring handle to make sure the spring has equalized and reached its full springback. Do not unwind the spring.

5.11 Note and record the total number of degrees of springback.

5.12 Cut the sample at the wire clamp and the right-angle bend.

5.13 Carefully slide the spring winder out of its bearings and remove the sample.

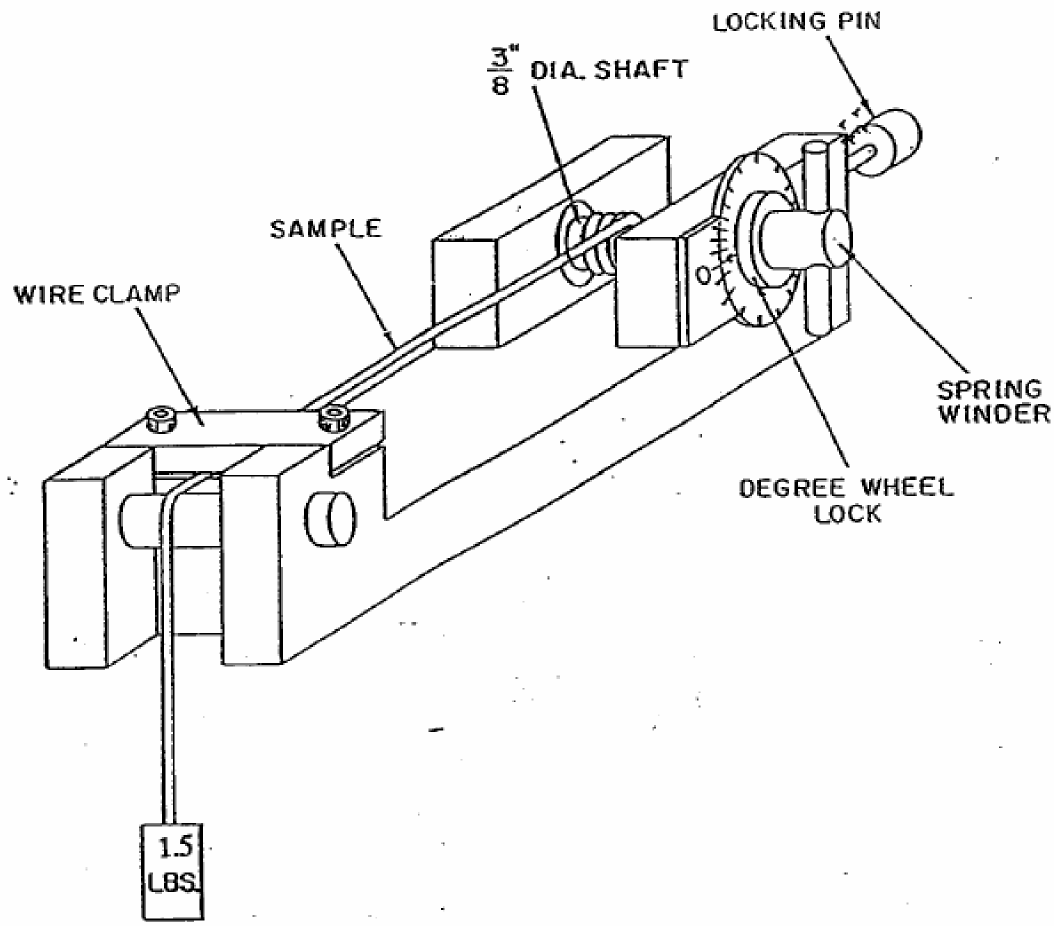
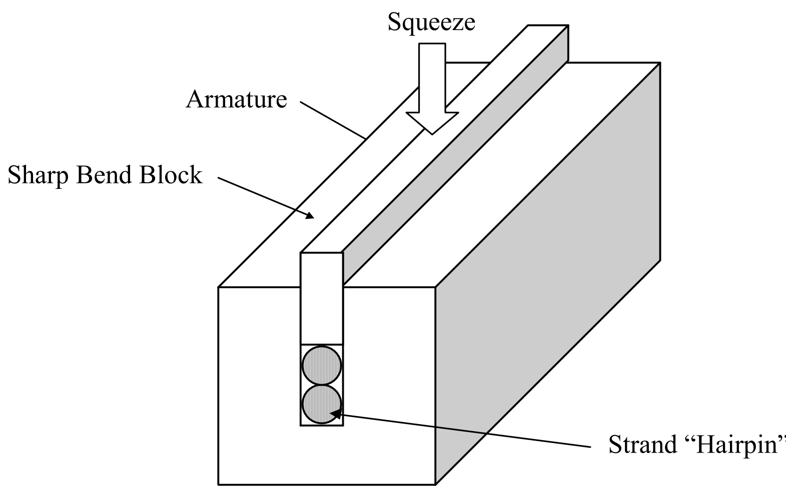


Fig. 8002 #1 Spring-back Test Fixture.

Appendix IV Sharp Bend Test

The sharp bend procedure is to simulate the deformation of the strand that may occur during cabling.

1. Fabricate a test fixture consisting of a slot in a metal block plus an armature that freely slides in the slot, as indicated in inset A1 below.



2. Cut a length of strand sample approximately 20 cm long. Bend the strand sample in half over a rod approximately 2 mm in diameter as indicated below.

3. Remove the rod and place the bent sample in the slot of the fixture as indicated in inset A1. Slide the armature into the slot of the fixture to squeeze the bent sample to the value of 2.6 mm (two strand diameters) to obtain a hairpin shape.
4. Examine the bend region at a magnification of at least 10X under a lighting level of at least 1076 lux and verify that the surface of the copper is not cracked, split, or otherwise deformed to prevent successful cabling.
5. Etch the bend region in dilute nitric acid and examine the filaments at a magnification of at least 10X and a lighting level of at least 1076 lux and verify that no filaments have been broken.